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ORIGINAL RESEARCH

THE DYNAMIC LEAP AND BALANCE TEST (DLBT): A TEST-RETEST RELIABILITY STUDY

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ABSTRACT

Background: There is a need for new clinical assessment tools to test dynamic balance during typical functional movements. Common methods for assessing dynamic balance, such as the Star Excursion Balance Test, which requires controlled movement of body segments over an unchanged base of support, may not be an adequate measure for testing typical functional movements that involve controlled movement of body segments along with a change in base of support.

Purpose/hypothesis: The purpose of this study was to determine the reliability of the Dynamic Leap and Balance Test (DLBT) by assessing its test-retest reliability. It was hypothesized that there would be no statistically significant differences between testing days in time taken to complete the test.

Study Design: Reliability study

Methods: Thirty healthy college aged individuals participated in this study. Participants performed a series of leaps in a prescribed sequence, unique to the DLBT test. Time required by the participants to complete the 20-leap task was the dependent variable. Subjects leaped back and forth from peripheral to central targets alternating weight bearing from one leg to the other. Participants landed on the central target with the tested limb and were required to stabilize for two seconds before leaping to the next target. Stability was based upon qualitative measures similar to Balance Error Scoring System. Each assessment was comprised of three trials and performed on two days with a separation of at least six days.

Results: Two-way mixed ANOVA was used to analyze the differences in time to complete the sequence between the three trial averages of the two testing sessions. Intraclass Correlation Coefficient ($ICC_{3,1}$) was used to establish between session test-retest reliability of the test trial averages. Significance was set *a priori* at $p \leq 0.05$. No significant differences ($p > 0.05$) were detected between the two testing sessions. The ICC was 0.93 with a 95% confidence interval from 0.84 to 0.96.

Conclusion: This test is a cost-effective, easy to administer and clinically relevant novel measure for assessing dynamic balance that has excellent test-retest reliability.

Clinical relevance: As a new measure of dynamic balance, the DLBT has the potential to be a cost-effective, challenging and functional tool for clinicians.

Keywords: clinical test, functional performance, postural control.

Level of Evidence: 2b

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INTRODUCTION

Balance is considered to be an important component of motor performance tasks. It is controlled by the central nervous system with the help of input from the visual, tactile, proprioceptive and vestibular systems.[1,2] There are two main types of balance, static and dynamic. Static balance is defined as maintaining postural equilibrium while holding the body in a stationary position and dynamic balance is maintenance of postural equilibrium while parts of the body are moving.[3]

Gambetta and Gray[4] refer to balance as the most important component in athletic ability because balance is involved in nearly every movement that is performed in daily life. There are a number of valid and reliable methods that are used in testing the static balance of a person such as quiet standing on a force plate in a laboratory setting or the Balance Error Scoring System (BESS) in a clinical setting.[5-7] However, these measures of static balance may not provide relevant information about balance capabilities required to perform dynamic physical tasks.[8]

One test that is extensively used in clinical and research settings for dynamic balance assessment is the Star Excursion Balance Test (SEBT).[5,6,9-12] Although the SEBT has been shown to be reliable and valid for identifying deficits in some musculoskeletal conditions, the movement tasks required during testing mimic only a limited number of activities involved in sports (e.g. ballet, gymnastics and ice-skating). Kinzey and Armstrong,[13] reported that the SEBT may not be appropriate for the clinical assessment of dynamic balance. Moreover, it was suggested that the reaching movements performed in the SEBT are not normal movements performed by the lower limb in the activities of daily living.[13] The authors recommended that normal functional movements (e.g. stair climbing, etc.) would be more appropriate for developing a dynamic stability test.[13] Another test that has been used to measure dynamic balance is the Modified Bass Test which requires leaping between marks on the ground, and trying to maintain a balanced position for five seconds with each leap.[1,3] Although this test requires base of support changes and alternate limb weight bearing, the hops require minimal effort and cannot be considered challenging for an active population.[1,3] Moreover, the test has standard jump distances that are not normalized to the leg length or height of the subjects.

In laboratory settings, time-to-stabilization (TTS) assessments including single jump landing onto a force plate are being employed for testing dynamic balance.[14] This testing method was able to demonstrate differences in dynamic balance between injured and uninjured populations.[14] Time taken by the participant to stabilize themselves on one foot after landing on the force plate from a jump was used as the dependent measure. Healthy subjects took approximately two seconds to balance themselves while subjects with chronic ankle instability (CAI) took approximately three seconds to balance themselves.[14] Unfortunately, force plates are neither prevalent, nor cost-effective in clinical settings.

Based on the literature, accurate, cost-effective and efficient clinically relevant tests that measure dynamic balance abilities during functional tasks that require alternating limb weight bearing and base of support changes are not currently available. Hence, the Dynamic Leap and Balance Test (DLBT) which mimics the movement patterns commonly involved in activities (e.g. walking, running, cutting etc.) performed in daily life and sports requires the controlled movement of body segments over a base of support that is serially changing with alternating limb weight bearing.

The DLBT is a low-cost clinical test based upon the concepts of previous balance tests such as the BESS, SEBT, TTS and the Modified Bass Test. The DLBT is a dynamic balance test that mimics normal activities of daily living and sport activities requiring serial changes in base of support, alternating limb weight bearing and a level of effort that should be challenging to an active population. The purpose of this study was to determine the reliability of the DLBT by assessing its test-retest reliability. It was hypothesized that there would be no statistically significant differences between testing days in time taken to complete the test.

METHODS

Participants

Thirty (11 females, 19 males) healthy individuals, from the university community (age 24.0 ± 3.1 years, height 172.4 ± 8.2 cm, mass 72.3 ± 14.2 kg) volunteered to participate in this study. Potential participants completed a self-report questionnaire regarding current and previous injury history. Participants were excluded if they reported current pain, numbness or paresthesia in the lower back or lower extremities, had a significant orthopedic injury of the lower back or lower extremity within the prior year (e.g. disc herniation, fracture, ligamentous sprain etc.), had a significant low back or lower extremity surgery within the prior year (e.g. ACL reconstruction, hip arthroscopy, lumbar laminectomy etc.), were currently under the care of a physician or seeking rehabilitation for a lower extremity or low back injury or pain, had a head trauma, concussion or were cognitively impaired within the prior six months, were currently experiencing any concussion like symptoms such as nausea, dizziness, headache etc., were currently experiencing balance problems, or were managing any neurological conditions e.g. stroke, Parkinson's disease, etc. All participants meeting the criteria for inclusion in the study gave informed consent after reading and signing forms approved by The Pennsylvania State University Institutional Review Board and prior to participation. Included participants averaged 6.06 on the Tegner Activity Scale.

Procedures

Participants were tested on two separate days with a difference of at least six days between the first and second test days. Participants were tested by the same investigator on each of the two testing days. The testing sessions were similar on both the days. On Day 1, demographic data (age, sex and physical activity level) was collected and anthropometric measures (height, mass, limb length, foot length) were taken. Dominant leg length was measured from the anterior superior iliac spine to the apex of the medial malleolus and foot length was recorded as well as shoe size. Leg dominance was determined by asking the participant which leg they would prefer for kicking a ball. Participants then rated themselves on the Tegner Activity Level Scale.[15]

On both days, participants performed the DLBT. This test incorporated the directional layout of the SEBT.[12,20] The pattern of the DLBT consists of 11 total targets in the same positional directions as the medial half of the SEBT for each foot, including one central target and two targets along each of the five directions i.e. anterior, anteromedial, medial, posteromedial and posterior for both the right (Figure 1a) and left (Figure 1b) limb. The directional lines were placed on a floor using 1 ½ inch cloth athletic tape with 6-inch diameter cardboard circles used to mark the center and peripheral targets. The short and long target distances for each participant were

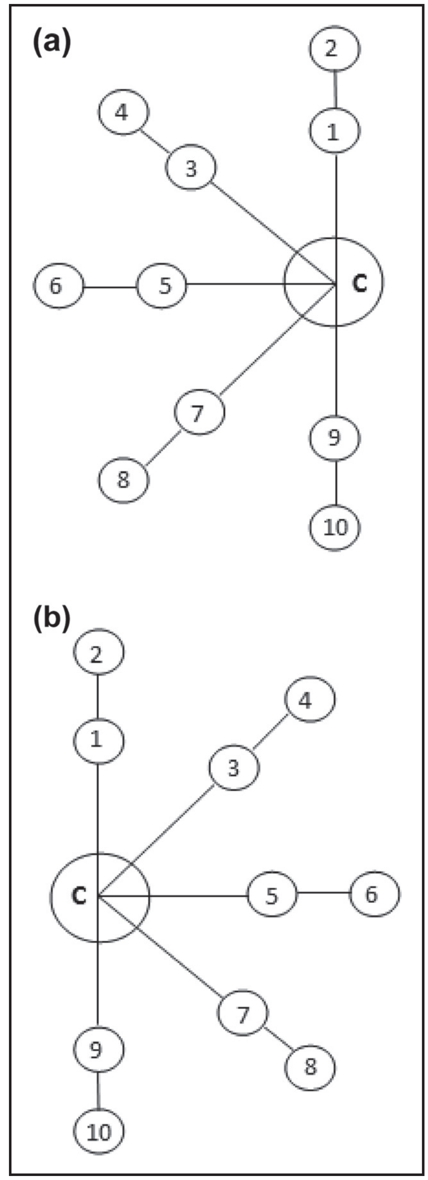

Figure 1. *(a) DLBT pattern for right dominant limb. (b) DLBT pattern for left limb dominant.*

DLBT = Dynamic Leap and Balance Test; (1) Anterior short, (2) Anterior long, (3) Anteromedial short, (4) Anteromedial Long, (5) Medial short, (6) Medial Long, (7) Posteromedial short, (8) Posteromedial long (9) Posterior short (10) Posterior long, (C) Central Target.

normalized using the participant`s measured leg length and normative data for the SEBT.[16] The proximal of the two peripheral targets was placed at 100% of the SEBT normative reach distance (expressed as a percentage of leg length) and the distal target was placed at 150% of the SEBT normative reach distance in each of the respective directions. The 150% target in each direction was included to make the task more difficult and encourage the participant to leap.

Participants began at the center target of the testing matrix standing on their dominant limb with the non-dominant limb foot next to the stance leg medial malleolus. The test was initiated by a verbal command of "Go" from the lead investigator. The participant then leaped from their dominant limb to a predetermined target landing on their non-dominant limb. The operational definition for a leap was "an acceleration or taking off from one limb and landing on the other limb". Once on the peripheral target, the participant immediately leaped back to the central target, landing on their dominant limb and trying to attain and then maintain balance for two seconds. Attainment of balance was assessed using criteria similar to the modified Balance Error Scoring System (BESS) criteria (1) touching down with opposite foot, (2) excessive hip abduction, (3) out of testing position for more than two seconds and/or (4) step, stumble or fall).[7] Once the investigator noted a restoration of balance for two seconds an audible command of "Go" was given to indicate the participant could leap to the next peripheral target. Participants continued this pattern of leaping and balancing for a total of 20 leaps (five directions and two distances in each direction). If the participant missed the target upon landing, they were instructed to reposition on the target as quickly as possible. All participants began with the anterior direction and moved in a clockwise (left leg dominant) or counterclockwise (right leg dominant) manner through all of the matrix directions, finishing after leaping from the posterior direction. In each direction, the participant leaped to the short target before the long target. Total time (seconds), to complete this task, was measured using a stop watch by the same investigator for each trial.

The DLBT was verbally explained to the participants and one demonstration of the test was provided. Participants were instructed to complete the DLBT as quickly as possible. The participants were given three practice trials before performing three timed trials. Two minutes of rest were provided between each of the practice and timed trials with five minutes of rest separating the practice and timed trials. Participants were allowed to wear their shoes and arm/hand position was unrestrained. The average time for the three timed trials was used for data analysis.

Statistical Analysis

A repeated measures two-way mixed ANOVA was used to calculate an Intraclass Correlation Coefficient $(ICC)_{(3,1)}$ to examine the test-retest reliability of the DLBT. Statistical analysis was performed using SPSS for Windows version 21.0 (SPSS Inc. Chicago, IL). Statistical significance was set *a priori* at $p \leq 0.05$.

RESULTS

Time values were Day1 49.55 ± 5.06 seconds, Day2 48.88 ± 4.31 seconds and an average time of 49.21 ± 4.61 seconds taken by participant on both testing days. There was no statistically significant difference between the three trial averages on Day 1 and Day 2 ($p = 0.054$)). An $ICC_{(3,1)}$ of 0.93 with a 95% confidence interval from 0.84 to 0.96 indicates an excellent level of test-retest reliability was achieved with the DLBT (Table 1). The Standard Error of Measurement (SEM) is 4.67 seconds and the minimally detectable change (MDC) is 12.94 seconds. Figure 2 displays a scatter plot of the correlation between testing results of the DLBT on Day1 and Day2.

DISCUSSION

DLBT was created as a measure of the type of balance and dynamic joint stability capabilities required in most activities of daily living and sport activities. This novel test demonstrated excellent with in the tester test-retest reliability ($ICC_{(3,1)} = 0.93$) that compares favorably to other commonly used measures of static and dynamic balance. It has been reported, that the intratester reliability of the BESS battery of tests that consist of six different static stance positions ranged from an ICC of 0.50 to an ICC of 0.80 for the individual tasks and an ICC of 0.74 for total BESS score.[17] Dynamic balance tests such as the Modified Bass Test[1] and the Y Balance Test™, a variation of the SEBT, is associated with respective intra-rater reliability ICCs of 0.82 and 0.85 to 0.91.[18]

Table 1. *Intraclass correlation between times of Day 1 and Day 2 of Dynamic Leap and Balance Test* (DLBT).*				
	Intraclass Correlation	95 % Confidence Interval		†Statistical Analysis
		Upper bound	Lower bound	p-value
ICC	.925	.848	.963	<0.01

* Values are the coefficient of reliability between the time taken on Day1 and on Day2
† Statistical Analysis performed using a one-way mixed ANOVA.
Significance was set at $p \leq 0.05$

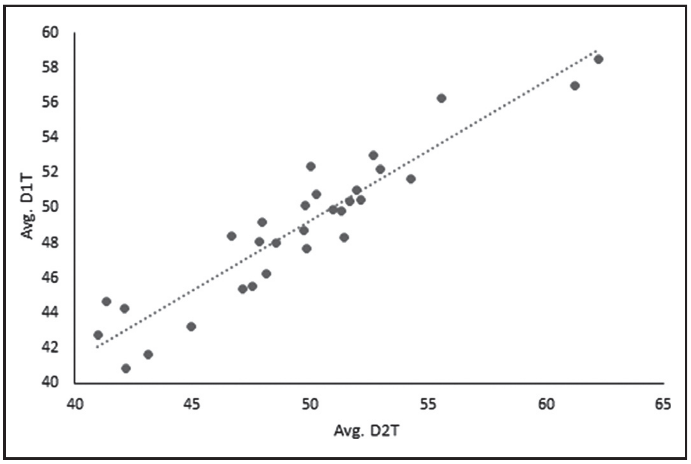

Figure 2. *Scatter plot showing correlation between the time taken by participants to complete the DLBT on Day1 with the time taken by participants on Day 2.*

Avg.D1T= Average time, in seconds, of three trials taken by participants on Day1 Avg.D2T= Average time, in seconds of three trials taken by participants on Day2 Pearson`s correlation coefficient r = 0.936.

A review of available, clinically-relevant, static and dynamic balance tests revealed a paucity of tests designed to measure dynamic balance capabilities required in common functional activities. Quiet stance tasks are commonly used to measure static balance capabilities while the SEBT[11,19] and Functional Reach Test[20] are commonly used to measure dynamic balance capabilities. The goal of quiet stance tasks is to maintain a prescribed posture and move as little as possible. Quiet standing balance tasks typically challenge the ability of the individual to maintain their center of mass in a position well within their base of support. The goal of the SEBT involves moving lower body segments as far as possible away from a stable and unchanging base of support while the Functional Reach Test has the goal of moving the upper body segments as far as possible away from a stable and unchanging base of support.[11,19,20] These tasks involve challenging an individual's limits of stability by moving their center of mass as close to their limits of stability as possible without losing balance stability.

An additional goal of dynamic balance tasks is to move along a self-determined pathway with as little variability as possible. In reality, both static and dynamic tasks are dynamic in the sense that they invoke movement at lower extremity joints. Quiet stance tasks invoke movement around the ankle joint(s) while dynamic tasks require movement around multiple lower extremity joints. The goal of the assessment is the differentiating factor between static and dynamic tests. Previous research suggests that balance capabilities may be specific to the imposed challenge, with static balance tasks being less able to identify balance deficits related to athletic injuries than the dynamic balance tasks.[21] This specificity may also be relevant when comparing dynamic balance tests. The reaching movements produced during the SEBT or Functional Reach Test may mimic activities performed in ice skating, gymnastics, dance or activities of daily living such as putting items into a cupboard, but do not represent the type of challenge presented to an individual's postural equilibrium and dynamic joint stability during activities like walking, running, and cutting. Instead of controlling moving body segments over a stable base of support, these activities/tasks require the individual to serially alternate their base of support from limb-to-limb requiring attainment of postural equilibrium with each change. It can be suggested that challenges to postural control may be unique to each type of task and therefore create the need for various dynamic balance tests that mimic specific activities. There is agreement with the assessment of Kinzey and Armstrong[13] that the SEBT does not mimic common functional activities.

Pionnier et al.[22] did kinematic analysis on reaching tasks of SEBT. They found that there was systematic trend of lesser joint range of motion (ROM) of ankle, knee and hip joints in a CAI group.[22] It is a possibility that limited ROM may be is a greater predictor for exhibiting lesser reach distances in CAI group rather than ability to maintain balance. However, when looking at the nature of the task of the DLBT, it appears that it is less likely to be limited by ROM which shows that the DLBT may be a more robust measure of dynamic balance.

There are a number of hopping tasks that are used in assessment with a variety of lower extremity pathologies and procedures such as anterior cruciate ligament reconstruction (ACL-R). Hopping tasks are most commonly used to measure strength and power post ACL-R as compared to a task that is specifically geared towards measuring or quantifying dynamic balance. Myer et al.[23,24] used various hopping tasks as a high-level power measure making them more of a strength measure than specifically a balance assessment tool. They can be helpful in giving some useful information regarding balance deficits but they are not specific balance assessment tools. Hopping tasks require propelling on and landing with the same limb which does not fully resemble functional activities like running, walking or cutting.[24] However, the leaping task involving reciprocal lower extremity movement in the DLBT more closely mimics walking and running activities. The tuck jump is another task that is used in the ACL-R population for assessing patient's landing mechanics in an effort to prevent further ACL injuries and assess the progress of rehabilitation.[25] It can be a good measure to reveal patterns of movement in lower extremity that may result in recurrent ACL injury after reconstruction but it may not be an appropriate tool for specifically assessing dynamic balance. Similarly, the tasks like bilateral squatting or step downs are used to assess the muscular strength and joint range of motion in the lower extremity.[26,27] However, neither of these tasks were originally designed to challenge the mechanisms that are involved in maintaining balance. The Vail Sports Test is another assessment test that involves functional activities against resistance.[28] However, like other ACL-R return to play assessment tools this task focuses more on assessing the muscular strength, power and endurance of the patient than balance.[28] Patients are graded on the basis of the strength, power and endurance they demonstrate during this task.[28] Although these strength, power and endurance assessment tools used with ACL-R patients are suggestive of the balance capabilities of a patient, they do not provide a specific assessment of the postural control system and are not designed to identify any postural control deficits. DLBT was created in an attempt to mimic the postural control challenges commonly encountered with functional activities such as walking, running and cutting.[29]

Balance requirements of common athletic activities such as running and cutting were assessed as a first step in the design of the DLBT. These tasks required the following: 1) an ability to maintain balance in single-legged stance, 2) an ability to change and reestablish a base of support from limb to limb without loss of stability, 3) incorporation of directional movements seen with running and cutting activities and, 4) incorporation of a physical effort challenge similar to walking, running and cutting. To assess an individual's ability to balance on one leg and change base of support from one limb to the other, the individual was required to attain a stable, quiet stance posture for two seconds every time they leaped to the center circle of the grid. This component was based upon the results of previous landing studies that utilized time-to-stabilization as a measure of postural stability.[14,29] It has been shown that healthy human participants take approximately two seconds to stabilize themselves on force plates during a single leg landing following a jumping task while participants with chronic ankle instability took longer.[14] The leaping movements used in the current study resemble the single leg landing task of previous studies making the two second stability requirement clinically relevant. The BESS criteria were used for qualitatively judging errors in stability and a stop watch for calculating total time. Participants were given a verbal cue to continue after they stabilized for two seconds in the central target. One half of the grid pattern utilized in the SEBT was used to ensure directional movements were similar to those encountered in walking, running and cutting. Finally, short and long leap targets representing 100% and 150% of average leg length normalized SEBT reach distances for each direction were included to make the test more challenging. The longer target distances requires the individual to explosively propel their body mass toward the target while leaping by creating forces of acceleration and then slow down the movement of their body mass during landing through the creation of significant deceleration forces. Additionally, to and fro changes in position to the targets at alternating distances also creates a greater challenge for the motor control system. These challenges are more similar to those experienced in running and cutting and require greater physical exertion than those encountered in the SEBT. It is hoped that this greater physical challenge will provide a more sensitive differentiating factor in identifying balance deficits.

A test of dynamic balance which more closely mimics the balance requirements of an individual's intended activity participation may possess greater ability to identify persistent balance deficits after injury or prior to participation. In prior studies, the SEBT has been used to identify differences in balance abilities in injured and non-injured populations.[19,30-32] It may be suggested that the DLBT will provide greater or additive differentiating power with regard to identifying dynamic balance deficits than the SEBT. The clinical utility of the DLBT, like the SEBT, would make it a valuable low cost tool for the clinical assessment of dynamic balance. Reviewing all these balance tests and functional assessment tools, it can be suggested that the DLBT comes out as an excellent addition to tools used for balance assessment. An effective progression hierarchy might be a BESS (static balance), SEBT (dynamic balance with unchanging BOS, limited by ROM) and the DLBT (dynamic balance with serial changes is BOS).

There were associated limitations with this study. This study was performed with only healthy adults for the purpose of establishing test-retest reliability. The results of this study can therefore not be generalized to other populations. Further examination of the DLBT in patient populations suffering from musculoskeletal disorders is required to establish validity and reliability.

CONCLUSIONS

Dynamic balance assessment is an important measure of the postural stability that provides valuable information about the balance deficits in injured populations. Unfortunately, there are very few clinically-relevant tests available to quantify dynamic balance. Furthermore, the tests available, such as the SEBT, do not appear to accurately mimic the dynamic balance requirements of common daily and sporting activities. The DLBT is a dynamic balance assessment tool that more closely mimics the challenges to dynamic stability encountered in common daily and sporting activities. The results of this study demonstrated excellent test-retest reliability for the DLBT. Further analysis of this testing procedure is required before its general effectiveness as a clinical measure of dynamic stability can be determined.

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